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APPLICATION OF THIN FILMS OF POLYTETRAFLUORETHYLENE COATINGS ON FERROUS MATERIAL

15 October 1959

DEPARTMENT OF THE NAVY
NAVAL WEAPONS PLANT

U.S. NAVAL WEAPONS PLANT

WASHINGTON 25, D.C.

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APPLICATION OF THIN FILMS

OF

POLYTETRAFLUOROETHYLENE COATINGS

ON

FERROUS MATERIAL

By

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ABSTRACT: Sandblasted and unsandblasted SAE 1020 steel panels were prepared for Teflon coatings. The surface roughness of the sandblasted panels was increased, over the original surface roughness, up to a roughness height rating of 124 microinches. All of the steel panels were coated with Teflon and then examined for quality of the coating. Three Teflon coating systems were used. The Teflon adhered well, up to a roughness height rating of 180 microinches, when the coated panels were subjected to a load. The coated panels, when exposed to an accelerated corrosion test, showed corrosion products after 24 hours. Data obtained in this investigation was used to revise NAVORD OD 10362, which is included as an appendix to this report. NAVORD OD 10362 is subject to additional changes as a result of current work.

ENGINEERING DEPARTMENT
U. S. NAVAL WEAPONS PLANT
WASHINGTON 25, D. C.

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(FORMERLY U S NAVAL GUN FACTORY)

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APPLICATION OF THIN FILMS OF POLYTETRAFLUOROETHYLENE COATINGS ON FERROUS MATERIAL

1. Teflon coatings were applied to SAE 1020 steel panels of various surface roughnesses. The results of tests on these panels are reported. This investigation was authorized by Bureau of Ordnance Task Assignment Number 804-188-81002-01047 of 11 August 1958.

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By direction

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INTRODUCTION

NAVORD OD 10362[1] was prepared as a procedure for applying Teflon, polytetrafluoroethylene resins, as coatings on steel surfaces for lubrication and corrosion protective purposes. This OD is not applicable as a general purpose document to govern the application of Teflon resins to ferrous materials. There are several Teflon resins, now produced, that are not included in NAVORD OD 10362. Also, no consideration is given to applying Teflon resins to unsandblasted surfaces: the surface roughness of the substrate, prior to sandblasting, is limited to a maximum roughness height average of 57 microinches[2].

In this investigation, steel panels were prepared with various surface roughness heights up to approximately 270 microinches. Various Teflon resins were applied as coatings on the panels; some of the panels were not sandblasted. These coatings were examined for such essential characteristics as appearance, thickness, porosity, corrosion resistance, and adhesion.

From the data obtained in this investigation, NAVORD OD 10362 was revised to make it a general purpose document for the application of Teflon resins to ferrous materials.

EXPERIMENTAL PROCEDURE

SAE 1020 steel panels, 6 x 4 and 6 x 2 inches, with various surface roughnesses were coated with three different systems of E. I. DuPont De Nemours and Co. (Inc.) "Teflon" polytetrafluoroethylene resins, Primer for Steels (850-201), One-Coat Enamel (851-204), and Gray Enamel (851-201)[3]. The Teflon coating systems were:

1. A primer coat and a gray enamel topcoat
2. A one-coat enamel coat, and
3. A primer coat and a one-coat enamel topcoat.

The surface roughness across the width of the panels had approximate average roughness height ratings of 10, 39, 70, 124, 173 and 255 microinches, as determined by a Brush Electronic Surfindicator. The instrument recorded, in microinches, the average height as a measure about an imaginary mean line parallel to the general direction of the profile of the surface, so that the sums of the areas contained between it and those parts of the profile which lie on either side of it are equal.

One-half of the panels at each of the various roughness heights were sandblasted with No. 87 silica sand at 90 psi before being Teflon coated. The other panels were Teflon coated without altering their surface roughness.

Only the primer coat and the gray enamel topcoat were used at all surface roughness values; the other coating systems were used only at the limits. It was considered not necessary to investigate the quality of the additional Teflon coating systems on the panels at all ranges of surface roughness as long as the conditions at the lim ts were satisfactory.

To prepare the panels for the coatings, all panels were degreased with acetone. The surface roughnesses were measured on both groups of panels, those that were sandblasted and those that were not, and then all the panels were stored in dessicators to prevent rusting.

When the panels were removed from the dessicators, they were cleaned with water-free xylene, dried by air blast, and then heated for 60 minutes at 700°F in a recirculating, hot-air oven that had been heated from room temperature to 700° ±5°F. This heat treatment served to oxidize the metal surface. Any gases or organic matter that might later be trapped between the substrate and the Teflon film and thus lessen the adhesion of the Teflon film to the substrate, were driven off. The panels were removed from the oven and allowed to cool to room temperature.

Immediately after cooling, the panels were sprayed with Teflon because they were not completely resistant to rusting or to contamination by foreign matter, and these conditions would decrease the adhesion of the Teflon film when applied later. The Teflon coating was applied with a DeVilbiss, TGA type spray gun, which was fitted with a No E90 nozzle. The spray gun was equipped with adequate oil, dirt, and moisture traps, and separators. The spray gun operating pressure was 30 to 40 psi; the gun was held 3 to 8 inches from the panels while spraying them.

For maximum adhesion of the Teflon coatings to the panels along with the polymerizing of the Teflon resins into a continuous coating, the Teflon resins have to be fused. When the temperature of the Teflon coated panels is raised above Teflon's melting point of 620°F, see reference 4, the Teflon resin particles fuse together. When the fused Teflon mass is quickly cooled, a Teflon film that is continuous and amorphous in structure forms the coating for the panels In this investigation, a fusing temperature of 700°F was used.

The minimum time that the Teflon coated panels remained at 700°F to obtain fusion of the resin particles was dependent upon the time that the metal-Teflon interface reached 700°F. Once the interfacial temperature reached 700°F, the fusing time was critical only when the substrate material was harmed due to prolonged fusing time. Some pieces that have thicknesses of 3 inches may require 1 hour of heating

Another important factor that had to be considered along with fusing was that the Teflon coatings had to be dried at a low temperature. At a temperature above 212°F escaping water vapor would cause pin holes in the Teflon coatings. In this investigation, all panels were dried at room temperature for 1 or 2 hours, and then forced dried in an oven for 30 minutes at 200°F.

As a result of the previous considerations, it was decided that the coatings would be applied to the steel panels in the following manner:

The panels with the first Teflon coating would be allowed to dry in the air at room temperature for 2 hours, and then baked in the oven at 200°F for 30 minutes before raising the oven temperature to 700°F for 30 minutes. The second Teflon coating would be allowed to dry at room temperature for 60 minutes, and further dried in the oven at 200°F for 30 minutes. The fusing time of these panels would be 45 minutes at 700°F. The fusing time was increased due to the low thermal conductivity of the first Teflon coatings.

To make sure that the previously described conditions were over the minimum for obtaining a fused coating, two panels were coated with Teflon primer and placed in the oven. The temperature was maintained at 200°F for 15 minutes, and then at 700°F for 15 minutes. The panels were cooled by a water spray. The Teflon was fused and could not be scratched off with the finger. This procedure also gave some idea of the thickness of the Teflon coatings.

The remaining panels were Teflon coated. They received a first coat of steel primer or one-coat enamel and were dried and fused as planned. Upon opening the oven, the panels were cooled with a water spray. The panels that had been coated with steel primer received a second coat of gray enamel or one-coat enamel. These panels also were dried and fused as had been planned. These panels were cooled by a water spray. All the coated panels were now ready for tests to evaluate the essential qualities of the coatings.

Some of the essential characteristics, which determined the quality of these Teflon coated panels, were appearance, thickness, adhesion, surface roughness, porosity, and corrosion resistance. The panels were examined for appearance by eye, and under 40 and 112.5 power magnification, to establish a limit of magnification below which the coated panels could be considered as having satisfactory coatings for lubricating purposes. The panels also were examined under 75 power magnification to ascertain, qualitatively, the adhesion of Teflon coatings to the substrate, and whether or not the Teflon coatings were fused properly. The thickness of these Teflon coatings was determined by Magne-Gage measurement, and the surface roughness was determined by a Brush Electronic Surfindicator. Evidence of porosity of the Teflon coatings was made by completing an electrical circuit through a drop of a salt solution placed on the coatings. Finally, some of the Teflon coated panels were tested for resistance to corrosion. These panels were subjected to a spray of 20 percent salt solution, see reference 5.

RESULTS AND DISCUSSION

All the Teflon coated panels, when examined by eye, appeared to be good, continuous coatings that were free from pin holes, cracks, pits, and blisters. Visual information like this can be used in routine acceptance tests; however, the Teflon coated panels in this investigation were also examined at 40 and 112.5 power magnification. This was done to find out if significant major defects in the Teflon films could be easily overlooked by the unaided eye or lower magnification, which would affect the lubricating qualities of the coating In addition, some idea of the texture of the Teflon films was observed.

At 40 power magnification, (1) the panels coated with the primer and the gray enamel appeared to have a coating made up of globules of Teflon, (2) the panels with one-coat enamel appeared to have a smoother surface than those with the primer and gray enamel, and (3) the panels with the primer and one-coat enamel topcoat appeared to have coatings similar to the one-coat enamel coating, but with a uniform pattern of raised brown fibers. No cracks, pits, pin holes, or blisters were observed in the coating at 40 power magnification.

At 112.5 power magnification, the texture of the Teflon coatings was similar to those viewed with 40 power magnification, except for the one-coat enamel topcoat on the steel primer. The one-coat enamel topcoat was discontinuous. The uniform pattern that had appeared as raised brown fibers was actually mud-cracking in the topcoat.

The adhesion of the Teflon coatings to the steel panels was tested qualitatively by using a shore Durometer Tester, type A. The Tester contained a conical probe which was retracted when pressed downward on a flat surface. The force exerted by the probe was approximately 80 psi. The tester was then slid along the panel in the direction of its longest dimension across the Teflon coating. Unfused or nonadherent coatings were visibly ploughed or removed from the panels. Satisfactory Teflon films were not damaged by the tester.

Two panels were coated with steel primer and a gray enamel topcoat. They were heated in an oven for 114 hours at 318°F. These coatings were easily removed from the panels with the Shore Durometer Tester. All the panels that were fused at 700°F showed no ploughing of the coating where the surface roughness of the coated panels was below 180 microinches. Those panels that were coated with a surface roughness of approximately 270 microinches also had fused, nonploughed coatings; but, at a few spots, the probe of the Shore Durometer tore the Teflon coating. This happened because the probe did not ride the profile of the surface exactly and was, therefore, not fully retracted. On very rough surfaces there was a shearing force exerted on the coating at the high spots of the panels All observations on the panels were made under 75 power magnification before and after using the Shore Durometer.

Table 1 shows the thicknesses of the different Teflon coating systems on the steel panels. For the primer and gray enamel, the thickness of the coating was approximately 0.50 mil. The one-coat enamel coating was approximately 0.20 mil. The primer and one-coat enamel coating thickness was approximately 0.30 mil. Each deposited Teflon layer was not to exceed 0.30 mil in order to lessen the chances of the films to mud crack. Also, the total film thicknesses were maintained at less than 1.0 mil. This was done because such Teflon films to be used as dry lubricants show minimum friction and maximum load carrying capacity, see reference 6.

Along with film thickness, surface roughness of Teflon films on roughened substrates was considered because of its effect on the selection of the surface finish of a production item. Table 1 shows the surface roughness of Teflon coatings on unsandblasted and sandblasted panels with various surface roughnesses. Note that the panels with initial surface roughness values of approximately 10 to 125 microinches showed an increase in surface roughness values after they were sandblasted. Panels with initial surface roughness values of approximately 175 microinches showed very slight change after sandblasting, see figure 1. Notice in figure 2, that after the panels were sandblasted, the change in surface roughness decreased with increased initial surface roughness.

The surface roughness was obtained on the unsandblasted panels and the sandblasted panels after they had been coated. The roughness of the unsandblasted panels with the primer and gray enamel topcoat showed a large increase on the coating as compared to the pre-coating roughness. This was evident in surface roughnesses up to about 80 microinches, see table 1. At 130 microinches and above, the Teflon coating roughness was about the same as the pre-coating roughness. For the one-coat enamel on the panels not sandblasted, the roughness of the coating was approximately 32 microinches, which was one-half of the increase of the roughness of the primer and gray enamel coating on similarly roughened panels. This phenomenon indicated that the one-coat enamel gave a smoother coating than the two-coat system of primer and gray enamel. Visual observation with magnification seemed to bear out this fact. The primer and one-coat enamel also showed an increase in roughness; but it was not evaluated because the crack in the topcoat observed under magnification might have affected the true surface roughness readings.

For the sandblasted panels, there was a slight increase in roughness of the primer and gray enamel coating over the roughness after sandblasting, see table 1. The roughness of the one-coat enamel coating was slightly less than that before coating. Since the thicknesses vary for the coating systems, it appears that roughness of the coating is less affected by the substrate roughness as the thickness of Teflon film increases.

Other tests were made on the Teflon coated panels to find out if the coatings were porous and corrosion resistant. Although these properties are closely interconnected in determining the quality of the Teflon coatings, they were treated separately in this investigation.

The Teflon coatings were examined for porosity. A drop of a electrolyte was placed on the Teflon coatings. The exposed underside of the coated panels was connected to the negative side of the source. When the electrolyte was touched with a platinum probe, connected to the anode that had an applied E. M. F. of 6 volts, gas bubbles formed in the electrolyte. Had the Teflon coatings not been porous, electric current would not have passed to enable the electrolysis of the salt solution.

An accelerated corrosion test was performed to obtain an indication of the corrosion resistance of the porous Teflon coated panels. The coated panels were exposed to a spray of 20 percent sodium chloride solution. All the panels showed pin point spots of corrosion products of the substrate after 24 hours in the salt-spray chamber. The test indicated the ferrous material below the Teflon coatings was attacked without any apparent damage to the Teflon coatings.

Table 1 - Surface Roughness and Coating Thickness Measurements

Panel No.	Average Surface Roughness Along the Width (microinches) As Received	After Sandblast	After Coating	Coating Thickness (mils)	Teflon Coating System
1	10	-	-	0.42	
2	10	-	-	0.38	
3	11	-	-	0.37	
4	10	72	-	0.34	Teflon Primer &
5	11	75	-	0.45	Teflon Gray Enamel
6	8	75	-	0.46	Panels 1-10
7	9	-	64	0.42	
8	9	-	63	0.43	
9	9	70	76	0.42	
10	9	70	84	0.60	
Aver.	10	72	-	0.43	
11	9	-	-	0.22	
12	9	-	-	0.22	
13	9	-	-	0.19	
14	9	63	-	0.22	Teflon One-Coat
15	9	70	-	0.25	Enamel
16	9	70	-	0.23	Panels 11-20
17	12	-	30	0.18	
18	12	-	38	0.20	
19	13	75	72	0.22	
20	13	75	72	0.17	
Aver.	10	71	-	0.21	
21	10	-	-	0.34	
22	10	-	-	0.30	
23	9	-	-	0.32	Teflon Primer &
24	9	63	-	0.32	Teflon One-Coat
25	9	72	-	0.30	Enamel
26	8	68	-	0.32	Panels 21-30
27	8	-	65	0.33	
28	8	-	65	0.28	
29	9	68	72	0.35	
30	9	68	75	0.32	
Aver.	9	68	-	0.32	

Table 1 - (Contd.)

Panel No.	Average Surface Roughness Along the Width (microinches) As Received	After Sandblast	After Coating	Coating Thickness (mils)	Teflon Coating System
31	39	-	-	0.45	
32	38	-	-	0.42	
33	42	-	-	0.57	
34	36	69	-	0.44	Teflon Primer & Teflon Gray Enamel Panels 31-70
35	38	59	-	0.42	
36	42	63	-	0.50	
37	41	-	84	0.58	
38	41	-	72	0.55	
39	35	78	80	0.56	
40	35	78	80	0.47	
Aver.	39	69	-	0.50	
41	70	-	-	0.66	
42	65	-	-	0.56	
43	75	-	-	0.45	
44	75	105	-	0.57	
45	75	110	-	0.42	
46	70	105	-	0.54	
47	65	-	79	0.45	
48	65	-	79	0.45	
49	70	90	85	0.38	
50	70	90	90	0.58	
Aver.	70	100	-	0.51	
51	125	-	-	0.58	
52	110	-	-	0.53	
53	135	-	-	0.38	
54	130	150	-	0.47	
55	105	125	-	0.48	
56	125	145	-	0.53	
57	130	-	130	0.62	
58	130	-	150	0.44	
59	125	135	130	0.57	
60	125	135	155	0.38	
Aver.	124	138	-	0.50	

Table 1 - (Contd.)

Panel No.	Average Surface Roughness Along the Width (microinches) As Received	After Sandblast	After Coating	Coating Thickness (mils)	Teflon Coating System
61	180	-	-	0.65	
62	165	-	-	0.73	
63	170	-	-	0.52	
64	170	155	-	0.45	Teflon Primer &
65	165	140	-	0.49	Teflon Gray Enamel
66	175	150	-	0.45	
67	175	-	180	0.52	
68	175	-	175	0.57	
69	175	150	150	0.48	
70	175	150	165	0.49	
Aver.	173	149	-	0.54	
71	250	-	-	0.50	
72	220	-	-	0.45	
73	210	-	-	0.45	
74	245	245	-	0.36	Teflon Primer &
75	225	220	-	0.38	Gray Enamel
76	240	235	-	0.35	Panels 71-80
77	255	-	250	0.54	
78	255	-	250	0.40	
79	250	250	250	0.49	
80	250	250	250	0.40	
Aver.	240	240	-	0.43	
81	270	-	-	0.21	
82	225	-	-	0.20	
83	225	-	-	0.21	
84	225	235	-	0.24	Teflon One-Coat
85	230	235	-	0.24	Enamel
86	245	250	-	0.20	Panels 81-90
87	280	-	265	0.17	
88	280	-	270	0.23	
89	280	290	270	0.28	
90	280	290	280	0.24	
Aver.	255	260	-	0.22	

Table 1 - (Contd.)

Panel No.	Average Surface Roughness Along the Width (microinches) As Received	After Sandblast	After Coating	Coating Thickness (mils)	Teflon Coating System
91	290	-	-	0.33	
92	290	-	-	0.31	
93	240	-	-	0.28	Teflon Primer &
94	270	260	-	0.30	One-Coat Enamel
95	270	260	-	0.32	Panels 91-100
96	280	260	-	0.30	
97	260	-	255	0.32	
98	260	-	240	0.35	
99	275	260	230	0.35	
100	275	260	240	0.35	
Aver.	270	260	-	0.32	

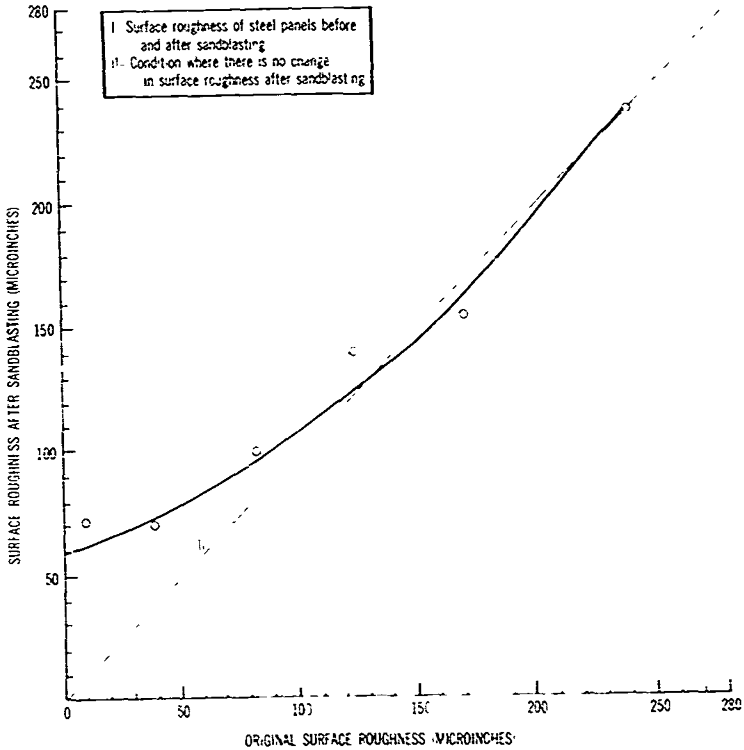

Figure 1 - Surface Roughness of Steel Panels Before and After Sandblasting.

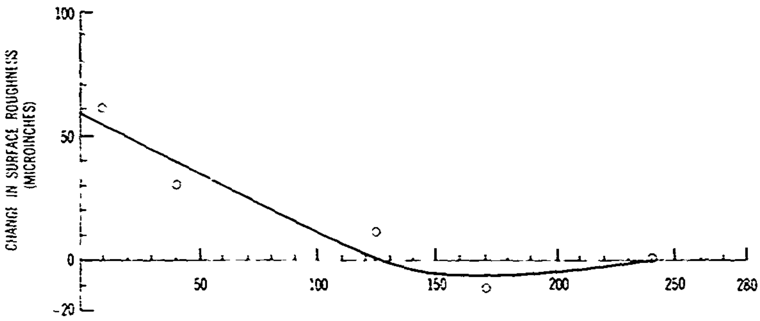

Figure 2 - Change in Surface Roughness of Steel Panels Due to Sandblasting as the Original Roughness of Steel Panels Increases

CONCLUSIONS

In this investigation, good adhesion of the Teflon coatings on sandblasted and unsandblasted panels with various surface roughnesses was obtained. The Shore Durometer which was used to qualitatively determine the adhesive quality of the Teflon coatings showed that the coatings were not damaged when they were applied on rough substrate, up to 180 microinches. At 270 microinches, however, the Teflon coatings were ruptured when subjected to the Shore Durometer Tester. It was not that the Teflon coating did not adhere well to the substrate, but that the Teflon coating on the very rough surfaces could not stand the shearing force of the conical probe of the tester when it was pushed across the coating.

All the panels with surface roughnesses less than 124 microinches showed an increase in surface roughness as a result of sandblasting. If contacting surfaces are to retain a high degree of smoothness, such surfaces cannot be sandblasted prior to applying the Teflon coating.

The Teflon coating on the panels afforded no outstanding resistance to accelerated corrosion conditions, however, the films were applied in a thickness that gave good lubricating qualities. Corrosion resistance of these coatings was secondary in importance to the application of the Teflon resins as dry lubricants.

RECOMMENDATIONS

Since Teflon is applied to ferrous substrates that vary in roughness, a study should be made to determine the wear resistance of the Teflon coating. This is of extreme importance to the designer who must specify the finish of contacting surfaces under various loads.

Tests in this investigation indicated that the Teflon coatings were porous. A study should be made to determine if this characteristic can be eliminated by altering the conditions by which the various Teflon resins are applied. Conditions which need to be considered are fusing temperature and fusing time - which affect the degree of polymerization of the Teflon resins, the rheology of the Teflon melts, and the degradation of the Teflon by pyrolysis.

Many Teflon primers and Teflon enamels are now available. These should be evaluated using compatible combinations, to compare their coefficient of friction, corrosion resistance, wear resistance, anti-sticking properties, adhesion, etc.

For testing the continuity of the Teflon combinations, development of a test is desired that could be used for general inspection of coated items.

ACKNOWLEDGEMENT

We thank Mr. V. G. Fitzsimmons of the Naval Research Laboratory and Mr. W. T. Talbott of the Naval Weapons Plant for their cooperation in this investigation.

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Appendix A

PROPOSED REVISION OF NAVORD OD 10362

PROCESS OF APPLYING THIN FILMS OF
POLYTETRAFLUOROETHYLENE RESIN COATINGS
ON STEEL SURFACES

1. INTRODUCTION. Teflon coatings are applied to steel surfaces to act as dry lubricating, anti-sticking and corrosion preventive coatings. Certain procedures and precautions are critical and strict adherence to the following procedures is required for satisfactory results.

Teflon coatings shall not be applied to steel pieces in which the final tempering temperature is less than 800°F. as these parts will be reduced in strength and hardness to a level which may be below the level required for satisfactory performance.

2. SURFACE PREPARATION. Preparation of the surfaces to be coated with Teflon is of extreme importance. The surfaces shall be clean, that is, free from dirt, grease, rust, mill scale, and any other materials foreign to the substrate. Preparatory to an oxidizing step, the material may or may not be sandblasted; however, sandblasting will considerably increase the surface roughness of very refined surface finishes. Dimensional requirements of material to be Teflon coated must be met prior to the coating step.

2.1 Non-sandblasting. Teflon shall be applied to unsandblasted surfaces where dimensional requirements are critical and cannot be changed, or where material is under no load and the economy of applying Teflon is to prevail.

2.1.2 Sandblasting. The substrate material shall be sandblasted with a clean, dry, mica free, silica sand. The sand may not be reused. The silica sand shall be no coarser than No. 80. Unless specifically authorized otherwise by the Bureau of Ordnance, NO OTHER MATERIAL MAY BE SUBSTITUTED FOR NO. 80, OR FINER, SILICA SAND. The dimensional requirements of the piece must be met after the sandblasting operation.

The proper sandblast pressure to be used varies with the type of equipment used and orifice size. The Naval Weapons Plant shall be consulted to establish this pressure. There is no delay permissible between the completion of sandblasting and accomplishing the oxidizing process, unless adequate provision is made to prevent the highly active, clean, sandblasted metal from corroding as a result of moisture contained in the atmosphere. If oxidizing is not to be accomplished immediately, the clean sandblasted material shall be stored completely submerged in dry unleaded gasoline. It is important that the gasoline be water-free, otherwise any water will promote vigorous metal interface corrosion at the water-gasoline interface.

2.2 Cleaning. Prior to oxidizing, the object shall be thoroughly washed with solvent to remove all oil, grease, dirt and/or sand particles, and then shall be completely dried by air blast.

NOTE: All air blast herein specified must be free of any oil, dirt, or moisture.

Solvents approved for use in the Teflon coating process are Xylene, unleaded water-free gasoline, and Varsol. All of these solvents are flammable. Xylene is rather toxic and is accumulative in the blood stream. No other solvent shall be used.

2.3 Oxidizing. After cleaning and drying, the object to be coated shall be placed in an oven preheated to and maintained between 700°-715°F. Heating from room temperature to 700°-715°F is also acceptable. The object is heated for only a short period at this temperature to drive off any gas inclusions or organic material, and to oxidize the metal surfaces sufficiently to increase the adhesion of the Teflon coating to be applied. Oxidation is complete when there is a slight change in color of the metal surface. An approximate time guide may be set up by using the time needed to bake the coating as being the maximum for oxidizing. (See 3.3.1.)

CAUTION: Do not exceed 725°F as higher temperatures may affect the physical characteristics of the base metal. (See 1.)

2.4 Cooling. After the oxidizing is completed, the objects are removed from the oven and air-cooled at room temperature for a time sufficient to bring the temperature of the object to approximately room temperature before the first coating of Teflon is applied. Oxidized ferrous materials show some, but not complete, resistance to atmospheric corrosion. To avoid contamination, rusting, and repetition of cleaning with solvent, the oxidized objects shall be coated as soon as practicable. If this can not be done, the oxidized objects shall be properly stored and protected.

2.5 Handling. Extreme care shall be observed after oxidizing to protect all surfaces from any foreign matter, contaminants, fingerprints, etc., during air-cooling, handling, removing from the oven, storing, and Teflon coating. Any fingerprints or foreign matter will prevent satisfactory adhesion of the Teflon coat. All objects shall be inspected in detail prior to Teflon coating to assure that the oxidized surfaces are completely clean. If any contaminant, fingerprints, foreign matter, etc., is present, the object shall be cleaned, as specified in 2.2, prior to Teflon coating. Clean rubber gloves must be used at all times when handling objects.

3. COATING. The coatings referred to in this publication shall be "Teflon" polytetrafluoroethylene resins, produced by E. I. DuPont de Nemours and Company (Incorporated), or equivalent. They shall be primers, enamels, clear finish, or any combination thereof as called for or as dimensional requirements will permit. Each Teflon layer, except black enamel, shall be between 0.0002-inch and 0.0003-inch fused film thickness. For optimum lubrication properties the total coating system fused film thickness should not exceed 0.0010 inch, although thicker films are advisable where corrosion protection is the prime consideration. When Teflon is applied so that it is sufficient to cause the substrate to become invisible, this will provide the required film thickness of between 0.0002-inch and 0.0003-inch.

> NOTE: Black enamel is an exception; it shows complete hiding of the substrate when a 0.001-inch layer covers the substrate.

Proper precautions should be exercised during the application of the Teflon resins and while the Teflon coated object is in transit from the applicating booth to the oven and vice versa to prevent various impurities and contaminants in the air from being physically trapped in the Teflon film and causing staining of the Teflon coat. Adequate air filtration and cleanliness should be employed at all times to prevent such staining.

3.1 Method of Applying the Coating. A few spray methods are known to provide satisfactory finishes and can be used. Mass production methods for producing Teflon-coated items can include ionizing or electrostatic spray apparatus as well as hand spraying methods, the latter will be described in detail.

A DeVilbiss TGA type gun with a No. E 90 nozzle may be used. The spray gun shall be provided with adequate oil, dirt, and moisture traps or separators. Prior to loading the gun, the Teflon is to be strained through a strainer to remove the larger particles which may affect the quality of the coating. Either unsized cheesecloth or a 150 mesh stainless steel screen shall be used for straining. Cotton fabric or sized cheesecloth shall not be used. The spray gun shall be filled at frequent intervals with smaller quantities of Teflon sufficient for coating uninterruptedly, the objects on hand rather than quantities in excess of immediate needs. During the spraying, the temperature of the Teflon in the gun shall not exceed 60°F. The gun should be operated without its fan and with an atomizing pressure between 20 and 25 pounds. After loading the spray gun, the spray should be adjusted to give the smallest quantity of fluid delivery possible. This will give a spray just barely visible to the eye. This type of spray is necessary to obtain a coating thickness between 0.0002 inch and 0.0003 inch, as described in paragraph 3.

3.1.1 Cleaning of Spray Gun. The spray gun shall be cleaned after use with hot water and rinsed thoroughly with acetone while still hot. The frequency of gun cleaning can be determined only by the operator. If the nozzle clogs frequently or a change in delivery volume of Teflon is noticed, the gun shall be disassembled and cleaned. The operator can control such maloperations appreciably by operating the gun with the minimum possible trigger action (i. e. motion of the control valve). Excessive trigger action will cause precipitation of Teflon at the delivery orifice. The Metal Finishing Guide-Book Directory 1959 describes the technique for using and cleaning the spray gun in order to obtain highest quality coatings.

3.2 First Coat. When applying the Teflon coat, all internal surfaces should be coated first, being careful to avoid excess buildup on the edges of holes, etc. Any excess buildup on the edges may be wiped off prior to applying the coat on the external surfaces. There is also a possibility of excess Teflon carrier liquid collecting in the bottom of dead-end-holes. This may be removed by a blast of air into such cavities.

Spraying just sufficiently to cause the substrate to become invisible will result in the film thickness required, see paragraph 3. This coat should have a dry, dull appearance and not a shiny, smooth deposit which is associated with paint spraying and which indicates an excessively thick coating.

The procedure employed successfully at the Naval Weapons Plant and at the Naval Research Laboratory utilizes the spray gun at a distance of from six to ten inches from the object. The proper technique for obtaining complete coverage and the required thickness can be obtained only by experience. Manufacturers engaged in applying coatings are to visit the Naval Research Laboratory and the Naval Weapons Plant to learn the technique employed at these activities.

3.2.1 Drying. It is essential that each coat be dried thoroughly prior to fusing in the furnace. However, drying must not be so rapid as to result in evolution of water vapor from the coating since this will cause porosity in the final fused coating. Objects are to be air dried at room temperature overnight or for approximately 16 hours. A satisfactory alternate to this method is a 10 minute air dry at room temperature followed by 30 minutes in a 180°F oven. Infrared lights may also be used provided they are far enough removed from the object to eliminate any possibility of too rapid drying. Under extreme humidity conditions, room temperature drying may not be effective and one of the other methods must be used.

3.2.2 Coating Removal. Any mistake made in applying a coat of Teflon may be rectified, prior to baking the coat, by removing the coat with a bristle brush and hot water. The object should then be thoroughly rinsed in solvent, completely air dried, and the coating reapplied. This treatment does not affect the oxidized finish of the object.

3.3 Fusing. Each separate coat of Teflon must be fused after being thoroughly air dried or forced-air dried. The coated object shall be baked in a furnace at a temperature between 700° and 725°F for a time sufficient to elevate the Teflon-metal interface to 700°F. At this temperature, the Teflon resin particles will fuse together to form the Teflon coating. It is essential that the Teflon-metal interface reach this temperature in order to obtain maximum adhesion of the Teflon film.

3.3.1 Fusing Time. The time required for fusing Teflon is determined by the rate of heating of the metal substrate. The time required to complete the process is dependent on the type and mass of metal in the object. Metal which is completely covered with Teflon requires more heating time than similar pieces which are only partially covered. This is due to the low thermal conductivity of Teflon. Therefore, more time is required to reach fusing temperature for subsequent coatings. The following list may be used as an approximate guide in determining the maximum time. The time indicated in each case is measured after the oven reaches 700°F.

Metal Thickness (Inches)	Baking Time (approx. minutes)
0 - 1/4	10
1/4 - 3/8	15
3/8 - 5/8	22
5/8 - 1	30
1 - 1-1/2	38
1-1/2 - 2	46
2 - 2-1/2	53

3.3.2 Fusing Oven. A recirculating hot-air furnace with an external heat source can be used for the fusing process to prevent localized over-heating of the Teflon to temperatures above the indicated furnace temperature. Experience at the Naval Weapons Plant indicates that random pieces from 1/8 inch to 3 inches may bake as long as 1 hour with satisfactory results on all objects when this type of furnace is used. However, excessive baking is to be avoided. Other methods of fusing, such as infrared, gas heat, and radio frequency heating are quite acceptable provided they raise the temperature of the Teflon-metal interface to 700°-725°F and maintain it there just long enough to fuse the Teflon. Localized overheating and excessive curing time change both the Teflon coating and the mechanical properties of the substrate. Ovens or furnaces subject to localized heating areas shall not be used.

CAUTION: When Teflon is heated above 400°F, small quantities of toxic compounds are given off. Adequate exhaust ventilation must be provided whenever Teflon is heated above this temperature. Smoking and flames in the vicinity of the spraying operation should be prohibited. Containers in which Teflon suspensoids are shipped have an attached warning of the hazards involved in the handling of this material. THIS WARNING SHOULD BE HEEDED. COMPLETE SAFETY PRECAUTIONS MUST BE FOLLOWED CAREFULLY.

3.3.3 Cooling. It is important that the objects be cooled as rapidly as practicable from 700° to 400°F to obtain a tough amorphous type of Teflon coat rather than a crystalline type which results from slower cooling. Rapid cooling of the objects after completion of fusing produces the desired tougher Teflon coating. To obtain this type of coating when the fusing of each coat is completed, the gaseous atmosphere in the furnace is quickly removed by exhaust ventilation, the furnace is opened, and the cooling process is started immediately. Objects may be water-cooled by submersion or by a heavy fog type of water spray having a fine dispersion of water. Objects may be water-cooled in the furnace; if not, remove the objects from the furnace and start the cooling process without delay. After the objects have been cooled to below 400°F, they shall be dried by airblast. The second coat may be applied when the objects have cooled sufficiently to permit handling comfortably by hand.

3.4 Repairs. If, after baking the coating, there is evidence of mud-cracks or high spots, these unsatisfactory surfaces may be repaired satisfactorily by wet sanding, using 500 or 600 mesh abrasive paper, before respraying the sanded area. The sanded area shall then be thoroughly washed with solvent to insure complete removal of all sandpaper particles and adhesive and thoroughly dried with an air blast. The sanded area shall then be resprayed, dried, fused, and cooled as described in 3.2, 3.2.1, 3.2.2, 3.3, 3.3.1, 3.3.2 and 3.3.3. Care must be exercised in removing unacceptable sections of coating to remove high spots or damaged areas and avoid sanding through the Teflon film especially at sharp edges. Use the same coating system and film thickness as before.

3.5 Second Coat. If no contaminant has come in contact with the first coat of Teflon, other than cooling water, the second coat of Teflon may be applied without cleaning the first coat with solvent. The second coat shall be applied in the same manner as the first, see paragraphs 3.2 through 3.3.3, except that the baking time should be increased by approximately eight or ten minutes because of the low thermal conductivity of the first coat. The correct thickness of the second coat can be determined only by experience; however, a change in color may be used as an indication, or use just enough of the sprayed Teflon to make the first coat barely invisible. The second coat shall be a maximum of

0.0003-inch thick, except black enamel coat, see paragraph 3. The combined thickness of the two coats shall be between 0.0004-inch and 0.0006-inch. Unless otherwise specified, the dimensions on the applicable design drawings apply to the original finish machined surfaces before sandblasting and Teflon coating.

3.5.1 Additional Coatings. Additional coatings shall be applied in the same manner as the second coating.

3.5.2 Buffing. After the last coat has been applied, baked, and cooled, it shall be dry buffed or polished using coarse canvas. Polishing compounds or high speed wheels for buffing shall not be used.

4. QUALITY. Acceptable quality is indicated visually by noting the completeness and consistency of film coverage, the adhesion of the Teflon to the metal, and the absence of dissimilarities in surface roughness of the coating, wrinkles or mud-cracks. The indication of fingerprints beneath the surface is objectionable but may not be critical. The coating must not peel or indicate rutting when scratched with the fingernail, especially along sharp edges.

5. TEFLON STORAGE AND HANDLING PRECAUTIONS

5.1 Shelf Life. The shelf life of the Teflon fluid under proper storage conditions, is approximately 3 months. For this reason, quart size containers or smaller should be purchased to avoid spoilage. Once the Teflon has precipitated out of suspension it cannot be recovered back into fluid suspension and shall be discarded.

5.2 Storage Conditions and Handling Care. The Teflon shall be stored at a temperature of 40° to 45°F at all times when not in use. Any Teflon subjected at any time to temperatures below 35°F or above 80°F shall not be used. As stated previously, the temperature of Teflon in the spray gun should not be permitted to exceed 60°F.

5.2.1 While in storage, the Teflon containers shall be turned over gently, approximately ten times each week to maintain proper suspension in the fluid. The container shall never be shaken vigorously and the contents shall not be stirred.

5.2.2 Prior to pouring the Teflon into the spray gun, the container shall be gently rocked back and forth. When loading of the spray gun is completed, the container shall be returned to cold storage or kept cool by other means such as under a cold water tap stream.

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NavOrd Report 6948
APPLICATION OF THIN FILMS OF POLYTETRAFLUOROETHYLENE COATINGS ON FERROUS MATERIAL, by J.H. Thompson and C.L. Scott. 15 October 1959. 23p., incl. table, illus. (NWPW-T-32-59)
(UNCLASSIFIED)

Sandblasted and unsandblasted SAE 1020 steel panels were prepared for Teflon coatings. The surface roughness of the sandblasted panels was increased, over the original surface roughness, up to a roughness height rating of 124 microinches. All of the steel panels were coated with Teflon and then examined for quality of the coating. Three Teflon coating systems were used. The Teflon adhered well, up to a roughness height rating of 180 microinches, when the coated panels were subjected to a load. The coated panels, when exposed to an accelerated corrosion test, showed corrosion products after 24 hours. Data obtained in

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2. Steel - Protective coatings.
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